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Electrical Current Generation Costs

We will now investigate the question of the electrical current generation costs for the examples just mentioned, and we will compare these with the current production costs for other types of generation plants.

The current production costs of various types of generation plants can be calculated using the following approximate formula

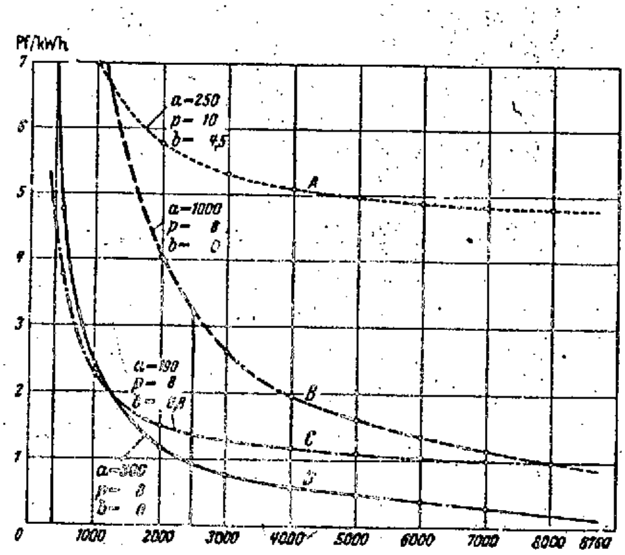
$$K = \frac{a p}{t_j} + b$$

Here a is the installation cost for 1 kW, p is the capital cost, t_j is the duration of use, referred to the installed power level, and b is the energy cost. The numbers for the installation costs given in Figure 6 are average values for hydroelectric plants and diesel generation plants. The coal generation plant has installation costs of 190 RM/kW *** which is an intentially low value and which will primarily be used for comparison purposes. 190 RM/kW probably represents a lower limit for a very modern high pressure coal generation station which will be realized only in the future.

* VDE, Berlin

** Numbers in the margin indicate pagination of original foreign text.

***RM = Reichsmark, prewar German currency (1 RM = 100 Rpf).



Hours per year

Figure 6. Comparison of power generation costs for various types of generation plants

A- diesel generation station, R, D hydroelectric generation plants; C- coal generation plant; a- installation costs RM/kW; b- energy costs Rpf/kWh; p- capital cost

In the case of a wind generation station, it is likely that one will have a tendency to consider the 300 RM/kW as much too low. However, there is a complete cost proposal containing offers of various large firms for one of the most well known projects. The final sum, including considerable amounts for unknown factors, amounts to about 18 million RM. The installed power level for this case is 60,000 kW. It is to be assumed that the first station built will require much higher costs, because many of the machines and devices have to be paid off first. Also there will be substantial increases for development work. In the comparison which we will make, we are dealing with costs for normal production generation plants. The capital costs are estimated in the usual way. The coal costs are very low and amount to 0.8 Rpf/kWh.

It is assumed that the actual electrical power generation costs are higher because of salaries, maintenance, insurance, taxes, etc. However, these items are almost the same for all types of generating stations, so that these additional costs have been omitted on purpose. Another reason for omitting them was that they are much smaller than the factors which are being considered. In the first example, we had a wind generation station about 100 m in height and with a wind-wheel diameter of 50 m. The operational time was 375 hours, calculated according to the installed power level. According to the diagram, the cost per kilowatt hour is higher than 6 Rpf for this maximum current production. If it is assumed that the installation costs are less for these small plants, for example around 200 RM/kW, then the production costs still amount to more than 4 Rpf/kWh. This clear calculation shows that even for maximum current production, such a generation station does not represent any savings compared with a modern coal generation station. It is not valid to say that one kilowatt hour is very expensive in peak load generation stations combined with a small time interval over which the current is offered, because the wind generation station cannot be used to meet the peak demand because of the unreliability of the wind. The time of the peak load is specified.

In the second example, that is for a high wind generation station with a height of about 500 m and a wind-wheel diameter of 160 m, we found that the useful time period was 2500 hours, which corresponds to 0.96 Rpf/kWh. The best equipped and cheapest coal generation plant would still have current production costs of 1.4 Rpf/kWh for this operational time period. However, we must consider the fact that the current production costs assumed here for the coal generation station are only valid to the point where the cable is connected to the switching installation. In the case of the wind generation plant, the control / 1405
costs and termination costs are already included. Therefore, if

it becomes possible to give off the entire amount of produced work to the consumer, then the high wind generation station would be superior to all other types of generation stations to a considerable degree because of the low current generation costs, provided that the current production times could be matched with the current requirement. This is one of the great weaknesses of the wind generation stations, which first makes it seem as though every wind generation station would have to almost 100% redundancy.

At first glance, this very substantial restriction would lead one to believe that wind generation stations cannot be economical in spite of the very low production costs. However, there are other arguments which will lead to a different opinion. First of all, it is possible to adjust factory production to the available power level and current type in many special situations. First of all, we can mention the very large scale projects which are planned in tropical areas which involve pumping large amounts of water in order to make agricultural land usable. Even in countries that have a well developed electrical power network it will be possible to incorporate the wind generating stations into the available facilities. The available generating stations have sufficient reserves and the network can provide for demand equalization. Usually hydroelectric stations are not analyzed alone, except if they are used for sawmills or other special cases. Instead they are usually considered in conjunction with other generating stations. If a wind generating station is operated in conjunction with a coal generating station, and if a wind generating station is exploited fully to provide the basic power requirements so as to fully exploit the wind energy, it becomes apparent that the basic power costs will be reduced. At the same time, the coal generating station will be used less and only to meet peak demand, which brings about a cost increase at the time of peak demand. However, a corresponding amount of coal has been saved and it can be used for other purposes. Considering our small oil reserves, this is quite important for our overall economy. Some countries have neither coal reserves nor hydro-electric power, nor oil reserves. Electrical energy production is always associated with foreign exchange losses. For such countries, economical production of electrical energy by wind generating stations will be vital.

Assuming that the aerodynamic observations are correct for a given country, a high elevation wind generating station with sufficient installed power level will certainly be economical. This is particularly true because the data obtained refers to areas having low wind intensities.

Construction Suggestions

One of the requirements is that the wind generation stations can indeed be built and that the technical details do not again compromise its economy. Some of the wind generation station projects are quite strange and even humorous. For example, one of the designers feels that the following idea is the only correct one: using two horizontal wind turbines installed on supports about 100 m high, he pumps water into a huge, high container. From it the water flows into a generation station with cups which then move and drive an infinitely long cord. This cord then drives a generator — there could be nothing simpler! — Another designer would build a 300 m high, round tower with a diameter of about 100 m. In the center of the upper platform there is a 150 m high, vertical and freely oscillating shaft which is driven by 8 horizontal wind turbines each having a diameter of 100 m. Not even considering the extremely difficult technical problems of supporting such a long shaft at one end alone and letting it oscillate freely, in such a construction the circumferential velocity of the wind turbines never becomes higher than the wind velocity. This means that even under storm conditions, the rotation rate is never greater than 8 rpm. If the rotation rate is increased by blades, then the wind will reach the interior of the construction and will produce vortices and opposing pressures. Even laymen will see that such a construction would not produce any appreciable amount of power. What should one say if the inventor, who is supposed to be an engineer, responds to the criticism by saying that it would be necessary to install three more turbines! Such constructions are not to be taken seriously and have damaged the ideas of wind power generation more than helped them.

Conditions are different for projects which do not have very high building heights and for which the installed power levels are maintained within certain small limits. Of course it is not difficult to build a 100 meter high steel tower and to install a 2,000 kVA power generator at the top of it and then to drive it by means of a large propellor. This tower must have sufficient strength to withstand the considerable weight and the considerable thrust applied to the turbine. In special cases, the installation could be economical for operational periods of 375 hours per year. Such a project is entirely possible. The rotation rate would have to be controlled and limited. This is probably the only difficulty associated with this type of construction.

Let us now consider projects which exploit the high altitude winds. All of the lattice tower constructions are very daring and we suspect there will be considerable difficulties associated with them. Specialists in steel construction state that such iron and steel constructions do, indeed, involve considerable difficulties, but that they are not impossible to construct. The fixed lower tower can be built without any problems or surprises. It must carry exceedingly high loads which are not rigidly connected with it. This leads to new problems. Most of the steel construction difficulties for high wind generation stations are associated with the moveable parts of the generating stations and their connection with the fixed part. New problems for the steel construction firms will be the support of the turbines, the erection of the generators, devices for avoiding excessive rotation rates, transfer between the operating position and the storm position, and the holding and control of large moveable weights. The structure must be extremely stable because of the extremely high pressures in the entire steel construction and in the bearings. It is possible that great weight savings can be made by using light magnesium.

Many researchers have pointed out the difficult oscillation problems for high masts with heavy tip loads. There is a danger of a synchronism of the eigen oscillations and the wind oscillations, which would result in a multiplication of the oscillation forces. According to some scientists, there will be no sum effect because the wind gusts are not periodic force excitors. The effects of frost have been greatly exaggerated. Even a large frost or ice deposit will be inconsequential because of the large masses involved.

The Electrical Equipment

If we now consider the electrical equipment of the high wind generation stations, we must first realize that all project designers have concentrated on steel construction, design of the drive turbines, their bearings and operation. This is probably related to the fact that none of the project designers were electrical engineers. Therefore, in general, conventional methods of power generation used in the electrical industry were assumed by the designers. This meant that no new problems were solved in the design in this area. The transfer of the power from the turbines to the generators is connected with several difficulties as can be seen from the designs. Usually these transfer problems were not worked out and if it was done, the result and the details were left out.

One plan suggests the use of large ring generators instead of the normal and commercial generators. These generators are something new and will now be discussed in some detail.

Let us consider a wind turbine which consists of two wheel systems rotating in opposite directions and whose propeller diameters are 160 meters. Inside this wheel system a ring generator is installed having a diameter between 40 and 60 meters. The power winding is connected with the windward side wheel and the excitation winding is connected with the wake wheel. The designer first wanted to give this generator ring a diameter of 120 meters because of static problems. Because of new calculations, the diameter was reduced to the value given above. In this way the generator is installed into the very strong and stable grid construction of the turbine. I believe that it is no longer necessary to consider the objection of many people that the 20 mm air gap with the enormous dimensions of the generator could be changed by mechanical influences, which could lead to damage. I do not believe it is important to any longer consider the deformation of the wheels because of mechanical forces, because of heat expansion, unbalanced magnetic forces, which would lead to considerable disturbances, because of the smaller diameter which has been adapted.

Figure 7 shows a cross section through the generator ring which has been redesigned in many ways recently. The electrical industry has presented similar designs as well, which, however, cannot be considered final designs. The figure can be understood if we consider the left part of the ring which is rigidly connected with the propellor construction of the windward side wheel which is located in the plane of the paper. The right part of the ring is attached to the wake side wheel and is perpendicular to the plane of the paper. The right part of the ring moves. It can be seen that the active part of a generator is located in a ring-shaped and completely enclosed cover. The ring gap is designed so as to resist water spray and is also used to remove hot air produced by the generator losses. There is a closed installation platform planned inside the windward side wheel from which the individual parts of the generator can be installed easily. Later on the control and maintenance work will be performed from this platform. All the work on the generator can be performed in a completely enclosed state without danger, in spite of the high altitude at which this work will be performed. Any technician can perform this work. There is no danger that the personnel will become dizzy. Of course connections will be provided for motors and lighting systems.

Since both wheels rotate, sliding contact rings will have to be provided for supplying the excitation current and for removing the useful current. Cables connect the windings and the sliding contact rings. They pass through the blades in the turbine wheels. Brushes remove the current in the usual way from the sliding contact rings, and the current is then transferred to the fixed part of the ring generation station. Of course the generator will have all of the installations required for monitoring its operation.

Some persons are concerned about frost formation in the generators. As long as the generators are loaded, it will not be possible for frost or ice to form because of the heat produced by the generators. Only when no heat is produced, for example during emergency repairs carried out during unfavorable winter conditions, can ice formation be expected. However, cheap heating units can be provided for the critical parts of the generator, which would solve this problem. The installation can be protected against atmospheric discharges by extensive grounding networks. Since the ring generator has no mechanical transfer elements, the efficiency of the installation increases.

The voltage and frequency of the current produced by wind energy is variable in all the projects. In the uncontrolled state, this current can only be used in exceptional cases. Therefore it must be controlled, unless the current can be produced in the form of direct current. Elastic control installations must be available for maintaining the frequency and the voltage constant. Control transformers and grid control are available for controlling the voltage. These devices are completely reliable. Up to the present time it has not been possible to transform an uncontrolled frequency into a controlled frequency. Therefore it will be necessary to install inverter installations so that a /1407
useful current with a controlled frequency can be delivered to the network. First of all there is a direct current intermediate circuit, in which the variable three-phase current is fed to grid-control mercury vapor rectifiers in the conventional way. After these rectifiers, there would be inverted converters which would have to operate in conjunction with regulating transformers. The power exchange between the generator and the network can be provided by a corresponding switching of the rectifier and the inverted converter.

We should also consider the use of an inverter installation without the direct current intermediate circuit, because we may then obtain a better efficiency. Because of the preliminary work already carried out by the electrical industry, it seems that it is quite possible to use inverters without the intermediate direct current intermediate circuit. We can expect that safe operational inverters having high efficiencies will become available for use in conjunction with wind generating stations.

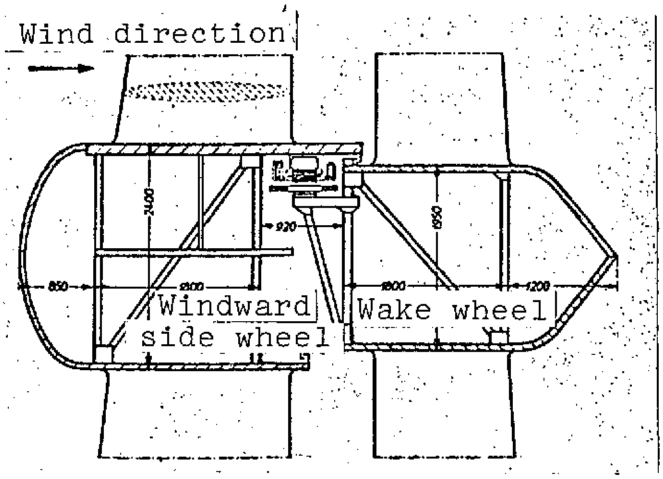


Figure 7. Cross section through a ring generator

In recent years, a great deal of work has been performed on the possibilities of exploiting wind energy. Many scientists have approved such projects. Nevertheless, the projects presented will remain questionable until large scale experiments are carried out. Only by accepting the risk of such large scale experiments will we reach the goal of producing electrical energy with wind energy. There are many difficulties associated with such a project.
It is very likely that the first useful generating stations will be quite different from what we imagine today, because technology is continuously advancing. The first locomotive, the first automobile, the first aircraft only represented the first steps in the development of a revolutionary development. We should have the courage to do this like our predecessors, so that the enormous possibilities of exploiting wind energy will become available to our economy.

Summary *

We may make the following statement regarding the problem of wind energy exploitation:

* Figures 1, 2, 3 and 7 were made available by Mr. Honnef.

1. The aerodynamic fundamentals from known works of aerodynamicists are found to be essentially correct according to recent experiments of the Reichs Weather Service.

2. There are difficulties associated with high steel towers carrying large tip loads, but they can be overcome.

3. Generators are either commercially available or can be built in the case of the ring generators.

4. There are still certain difficulties associated with controlling the frequency of the current, but these can be overcome.

5. Wind generating stations can be used economically for delivering current to normal power and lighting networks, but this must be done in conjunction with existing generating plants and equalizing networks.

6. In Germany, large amounts of coal can be used for more important purposes. Countries which have neither coal nor oil nor water resources can save considerable amounts of foreign currency by exploiting wind energy, assuming that some generating stations already exist.

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16. Abstract
Discusses the design and operational problems of wind power generating stations. Wind power generating stations are found to be economical for operation in conjunction with existing generating stations. Very large ring generator stations are described.

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